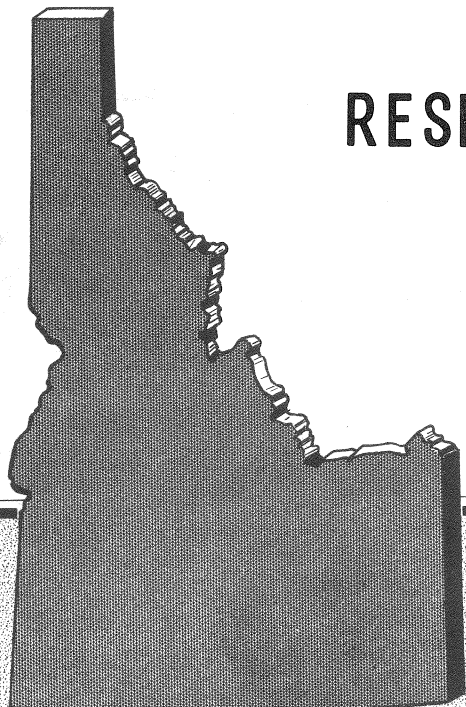
QUALITY CONTROL



RESEARCH PROJECT NO. 11

IDH-RP011

MAY 1967

STATE OF IDAHO DEPARTMENT OF HIGHWAYS

STATISTICAL APPROACH TO QUALITY CONTROL

Research Project No. 11

May, 1967

Materials and Research Division
Materials Section

State of Idaho
DEPARTMENT OF HIGHWAYS
Boise, Idaho

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The field work was done by Larry Hippler, Marvin Derrick, Jim Copley, and Bill Clark, Engineering Technicians, supervised by Gene R. Wortham, Engineering-in-Training. Gene R. Wortham and Robert D. Haye, Engineers-in-Training, wrote the report.

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Mr. W. A. Sylvies, Associate Materials Engineer at the Moscow Laboratory and Mac Sheesley, Assistant Planning Survey Manager helped in the statistical analysis of samples from Pit Le-111.

SYNOPSIS

The purpose of this quality control study was to make a realistic appraisal, using statistical methods, of our acceptance specifications for crushed mineral aggregate. Samples from two sources were tested for their (1) sampling variance, (2) testing variance, and (3) material variance.

A direct relationship was found between the sampling variance and sampling method. Samples obtained by means of an automatic sampling device produced lower sampling variances than samples obtained manually. Sampling variances also showed more uniformity when an automatic sampling device was used.

The splitting method used and the testing variance also showed a direct relationship. Samples which were cross-split (split twice and opposite quarters combined) showed a lower testing variance than samples which were split only once.

A discrepancy on sand equivalent values between the Boise and Moscow Laboratories was noted in the original test run. Moscow was biased on the low side by a value of 6.5. A set of reference check tests between the Boise, Moscow and Pocatello Laboratories also showed a slight variation to exist in sand equivalent values between the laboratories. The average variations in the reference check were: (1) 3.33 between Boise and Moscow with Moscow biased on the low side, (2) 3.43 between Boise and Pocatello with Pocatello biased on the low side, and (3) 2.63 between Moscow and Pocatello with Moscow biased on the low side.

STATISTICAL APPROACH TO QUALITY CONTROL

Introduction

The application of statistics to quality control is the use of this concept to help solve old problems. The purpose of a quality control program is to control the uniformity of materials and processes. Control is established through existing specification standards, and statistical concepts should be employed to obtain and maintain this control, and in preparation of new specifications.

A more realistic set of specifications could result using statistical analysis to determine specification limitations and acceptances. However, realistic specifications must acknowledge that some of the materials of processes will deviate from the normally accepted range of quality due to normal variations in sampling, testing, and in the material.

It should also be realized that non-destructive rapid field tests must be developed or adopted to keep up with progress in highway construction. Such test methods will enable inspectors to more effectively represent actual conditions.

The statistical analyses made on this study were used to determine existing variations in sampling, testing, and in the materials so this information can be used to properly evaluate our specifications, and test and sampling procedures.

Aggregate samples were obtained from two crushers and analyzed for variance, which is a measure of the distribution of measured quantities about some average value. The variances were isolated by cause and magnitude. The three variances studied were (1) testing, (2) sampling, and (3) material.

Samples from a crusher near Salmon, Idaho, were obtained by hand; whereas, an automatic sampling device was used for sampling from a crusher near Jerome, Idaho. The samples from Salmon were tested in the Boise Laboratory. Those from the Jerome source were tested in both the Boise and Moscow Laboratories.

Conclusions

1. Automatic sampling devices produce lower sampling variances and should be required for sampling whenever feasible, particularly at crushing and screening plants.
2. Cross-splitting produces a lower testing variance and should be a standard procedure in the splitting of materials samples.
3. Of the overall variance, testing variance comprises approximately 17 per cent, sampling variance 30 per cent, and material variance 53 per cent.

Recommendations

1. Use of an automatic sampling device for all sampling, permitting the cutting of several portions from belt to construct a single sample.
2. Use of cross-splitting method in splitting of samples.
3. Development of new field sampling methods to insure proper and unbiased sampling.
4. Continue the reference sample program between laboratories to maintain an acceptable level of confidence in laboratory testing results.
5. Recognize valid testing variances in specification limits set forth.

6. Continue investigating variations in materials to permit the writing of more realistic specifications.

Concepts of Statistical Analysis

To get a representative sampling of the crushed aggregate, it was decided that 50 duplicate samples were needed over approximately 5,000 tons of material at each pit. A duplicate sample means that two separate sampling bags were filled with material as close as possible to the same point in time. The samples were analyzed for testing, sampling, and material variances. Each variance (sampling, testing, and material) was isolated from the other two in the program so that their magnitudes could be examined.

Each pair of samples consisted of approximately 100 lbs. of material. The duplicate samples were termed D_1 and D_2. The D_1 and D_2 samples were then divided into A and B portions after being received at the laboratory. In all cases, the D samples were placed into the splitter directly from the sample sacks. Therefore, for each duplicate sample there would be four portions available for testing, i.e., D_1A, D_1B, D_2A and D_2B. See Figure 1 for schematic diagram of this procedure.

After all the samples were tested, analysis was made for the testing variance, sampling variance and material variance. Testing variance refers to the variance arising from the inability to produce the same laboratory results from what is considered to be identical samples. It is the difference between the A and B portions in Figure 2. Sampling variance arises from the inability to procure an identical sample each time in the sampling procedure from the same lot. It is the difference between the D_1 and D_2 samples in Figure 2. Material variance is due to the difference between individual samples. This difference is calculated from average test values of each sample as shown in Figure 2.

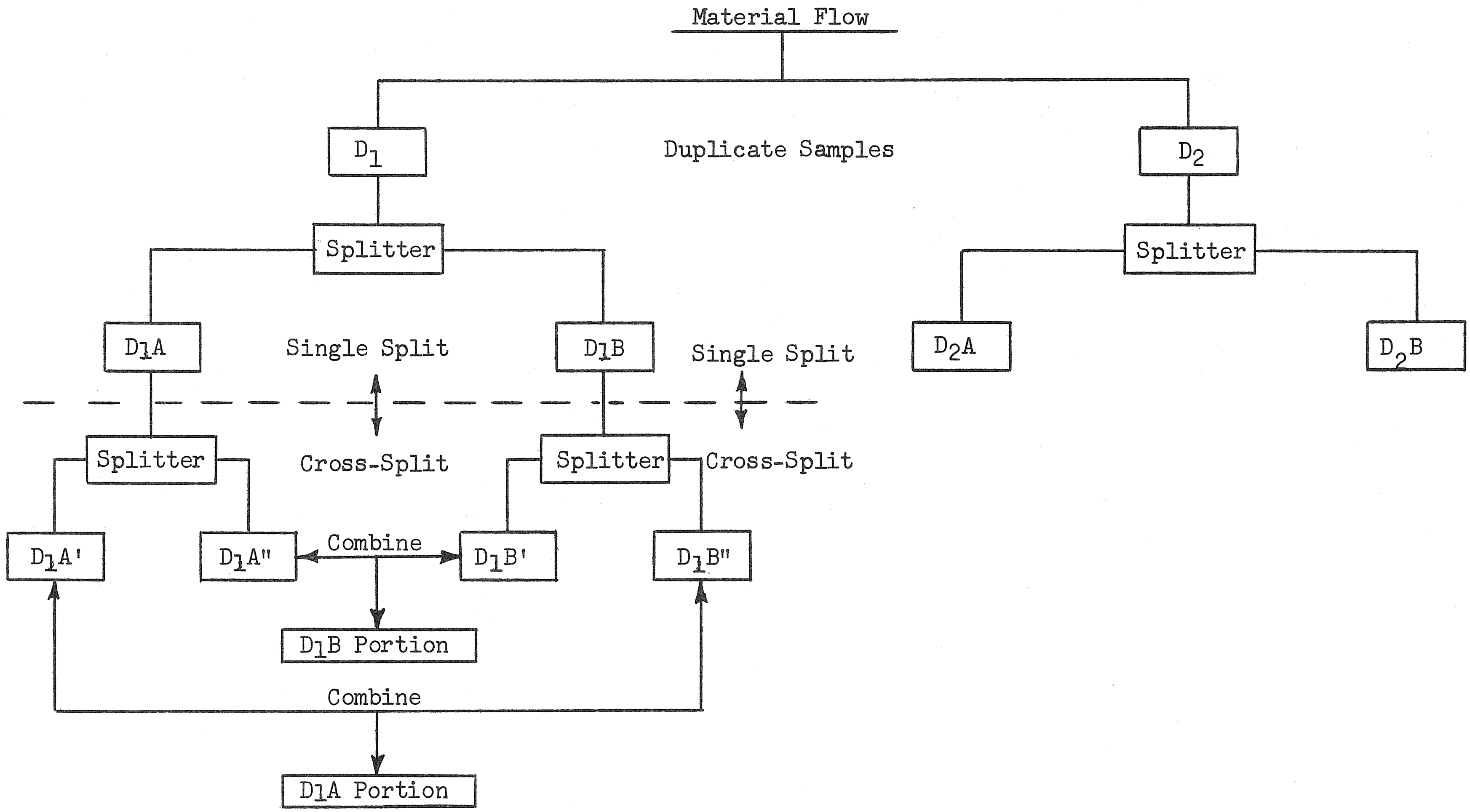
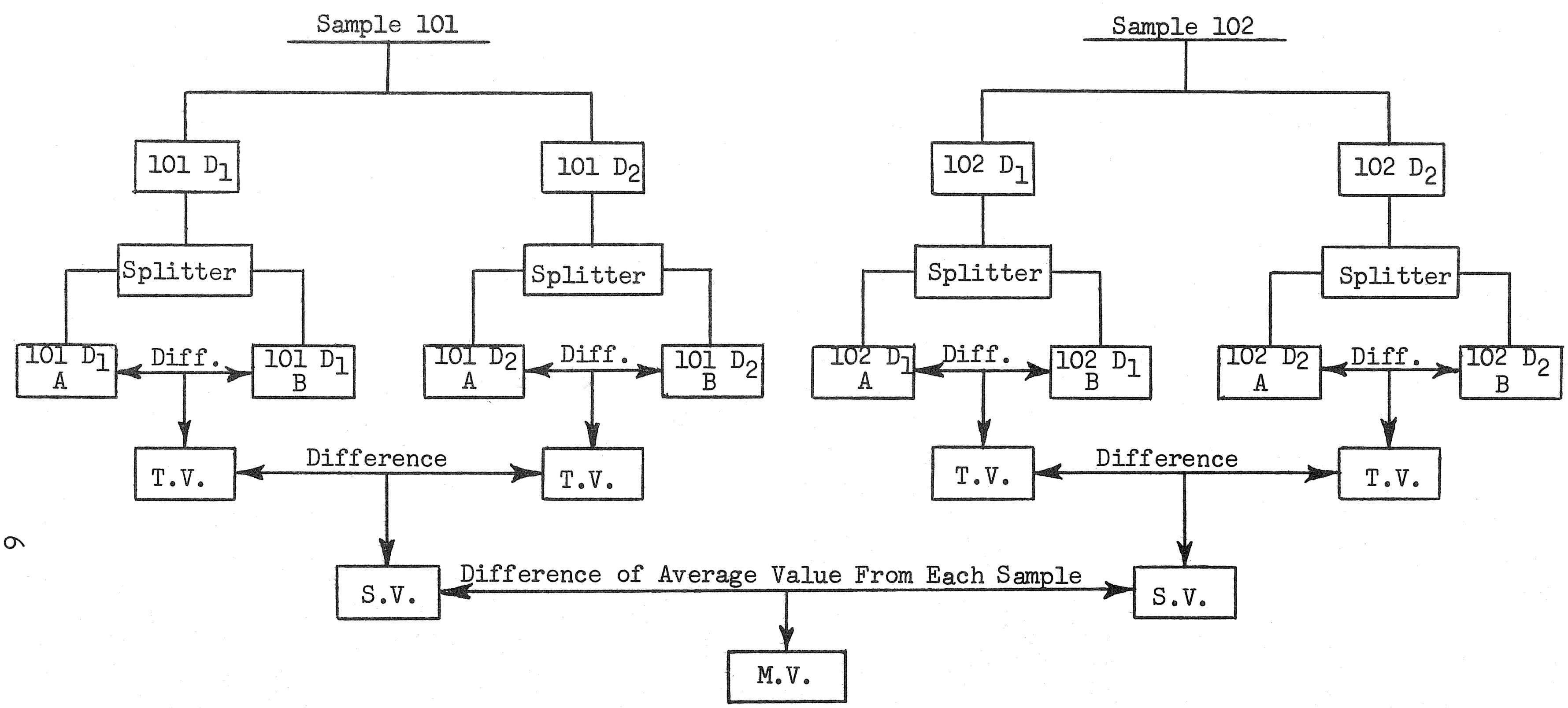


Figure 1 - Schematic Diagram of Sampling and Splitting Method



T.V. = Testing Variance

S.V. = Sampling Variance

M.V. = Material Variance

Figure 2 - Comparison of Samples for Variance

Sampling Methods

Two sources were selected for this study, Pit Le-111 at Salmon, Idaho, and Pit Jr-2 at Jerome, Idaho.

The crusher at Pit Le-111 was sampled by a manual method. Samples were obtained at intervals, 5 to 20 minutes, from a conveyor belt between a storage hopper and the point of loading trucks. The belt was stopped at each sampling interval. There was a distance of approximately six inches between duplicate samples. Figures 3 and 4, pages 8 and 9, show the sampling method and equipment.

Owing to crusher breakdown, only 34 duplicate samples instead of the planned 50 were obtained through production of approximately 2,000 tons of aggregate. The sampling was also affected by gusty winds which blew aggregate dust through the area. Sampling was conducted over a 1½ day period. Table 1 (Appendix) shows the sampling schedule.

The material from Pit Jr-2 was sampled by an automatic sampling device with an approximate two-minute lag between duplicate samples. This device was electrically operated with the sample bucket cutting the entire width of flow of material. Figure 5, page 10, shows the installation and operation of the sampling device. A single sample was made up from the material obtained by passing the sampler through the stream of material from the belt eight times. The sampling schedule was based upon a table of random numbers.* Using the output rating of the crusher, 50 consecutive random numbers were selected and multiplied by the number of hours necessary to yield 5,000 tons of material. The sampling schedule was then set up according to time intervals between samples rather than a continuous time schedule. In this manner, equipment failure did not affect the sampling time schedule. Table 2 (Appendix) shows the dates and times at which the 50 duplicate samples were taken.

* Random number tables may be obtained in most statistical books

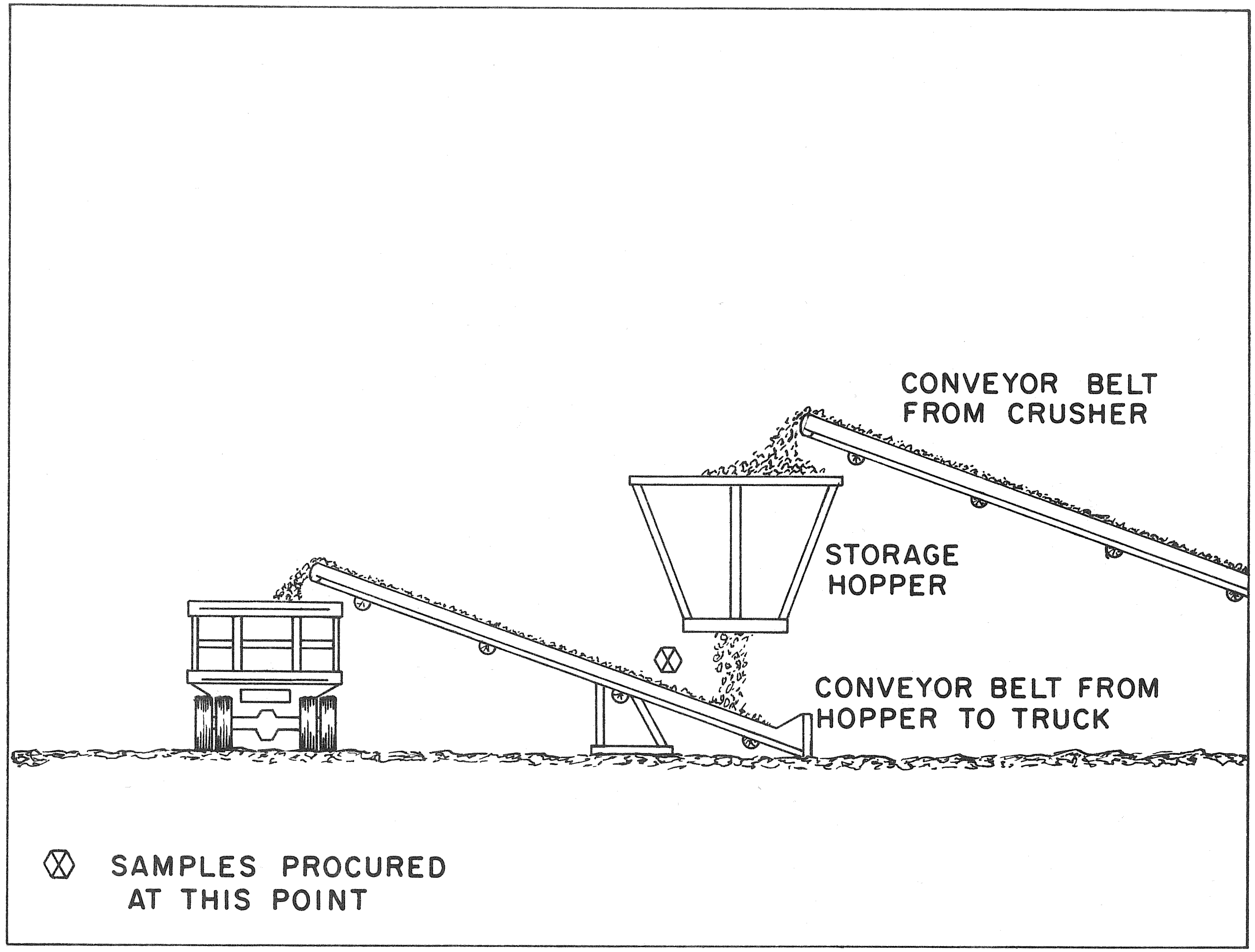


Figure 3 - Point of Sampling in Crushing and Feeding Operation

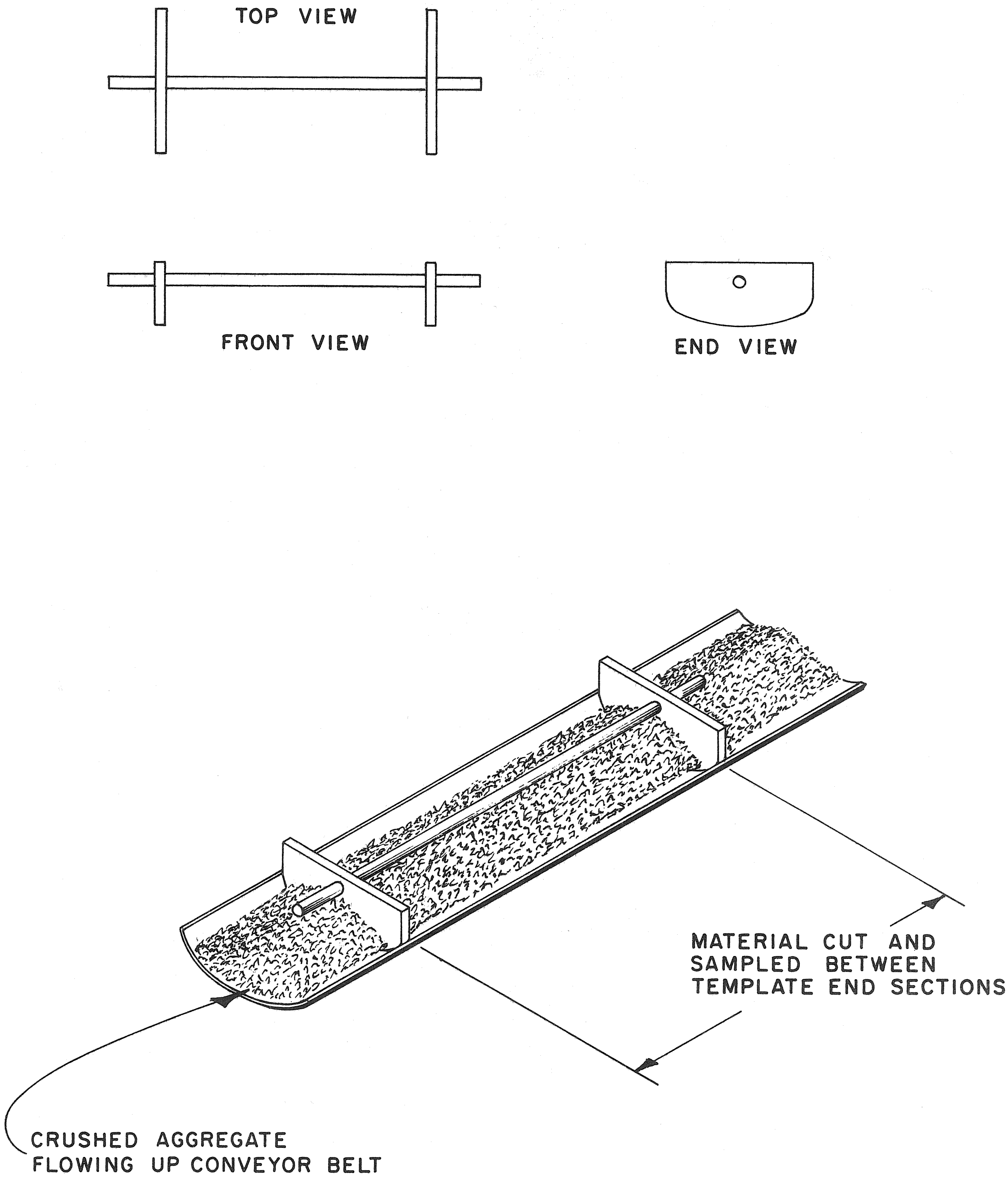


Figure 4 - Sampling Device

Figure 5 - Installation and Operation of the Automatic Sampler at Pit Jr-2

Testing of Samples

Samples were tested at both the Boise and Moscow Laboratories, Le-111 at Boise and Jr-2 at Boise and Moscow. The samples were tested for the arithmetic average, material variance, sampling variance, testing variance, overall variance, and overall standard deviation values for the gradation and the sand equivalent. The gradation analysis was run on the per cent passing the 3/8 in., No. 4, No. 8, No. 50 and No. 200 sieves. Because of the wide variation in per cent passing the No. 4 sieve, the No. 8, No. 50 and No. 200 sizes were based on 100 per cent passing the No. 4 sieve.

Coarse aggregate at the Boise Laboratory was graded with a Wheeler Shaker and in the Moscow Laboratory with a Gilson Shaker. Other laboratory testing equipment was the same.

The 34 duplicate samples from Pit Le-111 were all tested at the Boise Laboratory. They were cross-split, using a mechanical splitter, into A and B portions. Cross-splitting is similar to quartering material on a mat and then combining the opposite quarters to form a single sample. This splitting procedure is illustrated in the lower portion of Figure 1, page 5. Cross-splitting was used in a definite attempt to insure that the A and B portions were as nearly identical samples as possible. The statistical results of Le-111 testing are shown in Table 3 (Appendix) together with the 1, ±1, ±2 and ±3 standard deviations.

The 50 duplicate samples from Pit Jr-2 were evenly divided between the Boise and Moscow Laboratories for testing. Table 4 (Appendix) shows the distribution of samples between the two laboratories. Listed under "Boise D_1 and D_2" are the duplicate samples tested in Boise; those listed under "Moscow D_1 and D_2" being tested at Moscow. Under the "Boise-Moscow D_1 and D_2" column are listed the remaining duplicate samples, divided between, and tested at both Boise and Moscow.

Tables No. 5 and No. 6 are a compilation of the results of the statistical analysis of the tests of Pit Jr-2, including a Boise-Moscow (combined) column, which is the statistical analysis of all samples run, regardless of where tested. A complete statistical program was run on the data in each of the columns (Boise, Moscow, Boise-Moscow and Boise-Moscow Combined) using four separate computer runs.

Duplicate samples from Pit Jr-2 were only split once. The results of testing from Pit Jr-2 are shown in Tables No. 5 and No. 6. (Appendix).

Samples 117D and $117D_2$ were omitted from the 3/8 in. and No. 4 run on Pit Jr-2 due to the large discrepancies between these test values and the other data. Samples 132D and $132D_2$ were omitted from the sand equivalent on the same pit for the same reason. It is believed that these samples were tested improperly or the error was due to the handling or testing rather than an unbiased deviation.

Table 7 (Appendix) shows the coefficient of variation for the Boise and Moscow Laboratories. The variations are between test results at each laboratory and not for test results between laboratories.

Discussion

The conclusions of this study were based on the gradation analysis because of the close agreement in Jr-2 gradation values (see Table 5 Appendix) between the Boise and Moscow Laboratories. Unless otherwise noted, the Jr-2 values in this section are based on all the samples, regardless of which laboratory did the sampling.

Gradation

The testing variances are shown in the following table using data from Table 8 (Appendix) on testing variance comparisons.

Grain Size	Pit Le-111	Pit Jr-2
3/8 in.	0.30	4.16
No. 4	0.42	3.67
No. 8	2.41	1.48
No. 50	0.82	1.00
No. 200	0.40	0.52

As shown in the table, the testing variance for the 3/8 in. and No. 4 material from Le-111 is considerably smaller than Jr-2. This wide difference is believed to be due to the splitting methods used. Material from Le-111 was cross-split where material from Jr-2 was single-split. To remedy this condition, it is recommended that cross-splitting be used in the splitting of material. Test results from Le-111 indicates that cross-splitting will produce a testing variance for gradation of approximately plus or minus one per cent where Jr-2 results indicates testing variance of approximately twice this amount.

The gradation analysis between the Boise and Moscow Laboratories on Jr-2 material supports the recommendation that cross-splitting is the best method. For this series of tests, Boise test samples were single-split whereas Moscow test samples were cross-split. The testing variance of the two laboratories are shown in the following table.

	Jr-2	
Grain Size	Boise	Moscow
3/8 in.	6.37	2.49
No. 4	5.16	1.89
No. 8	1.29	2.09
No. 50	1.13	1.03
No. 200	0.60	0.43

With the exception of the No. 8 material, the Moscow testing variances are lower.

Sampling variance comparisons are shown in Table 9 (Appendix) and in the following table.

Grain Size	Pit Le-111	Pit Jr-2
3/8 in.	7.38	1.26
No. 4	22.93	2.16
No. 8	4.03	0.95
No. 50	3.40	1.40
No. 200	1.29	1.91

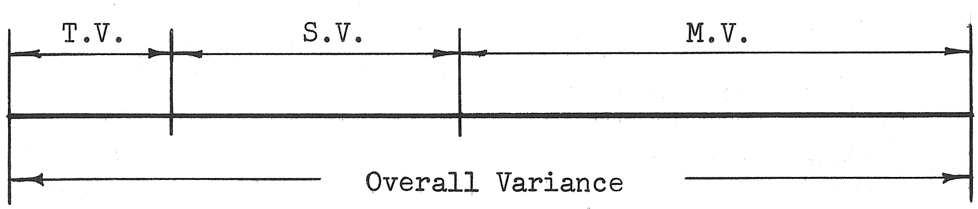
Samples from Jr-2 were obtained using an automatic sampling device. Le-111 was sampled manually. The sampling variances for Jr-2 are relatively small and much more uniform when compared to those for Le-111. It is believed that this is because eight passes of the sampler through the stream of material from the belt were required to obtain a single sample using the automatic sampler while a single large portion of material taken from one section of the belt made up each sample taken manually. This indicates that manual sampling caused more variance and deviation in the sampling variances than sampling with the automatic sampling device when done as described. An automatic sampler should, therefore, be required for sampling whenever feasible, particularly at crushing and screening plants. The results of tests on samples from Pit Jr-2 indicate that the sampling variance should be approximately plus or minus two per cent.

The material variance comparison is shown in Table 10 (Appendix). The material variance ranges from 0.52 to 40.38 for Pit Le-111 and from 1.23 to 21.98 for Pit Jr-2. It is difficult to state what may cause the fluctuations in the material because there is no way of knowing just what amount the material actually varies. We would expect the material variance to represent variations in the pit or quarry, and in the crushing and screening processes. Because of this doubt, the material variance has more meaning when it is expressed as a percentage of the overall variance after the testing and sampling variances have been isolated. This would give a clearer understanding as to just how much of the overall variance is due to the material.

The following table shows the material variance as a percentage of the overall variance.

	Le-111		Jr-2	
Grain Size	Overall Variance	Material Variance as a %	Overall Variance	Material Variance as a %
3/8 in.	22.13	65.34%	18.82	71.20%
No. 4	63.73	63.36%	27.81	79.04%
No. 8	9.29	30.57%	8.69	72.04%
No. 50	5.88	28.23%	6.92	65.17%
No. 200	2.21	23.53%	3.66	33.61%

The material variance is generally the largest portion of the overall variance followed by the sampling and testing variances in that order. The relationship of the three aforementioned variances to the overall variance is shown in the following line diagram.



On the basis of the test results, testing variance comprises approximately 17 per cent of the overall variance whereas the sampling and material variances comprise approximately 30 per cent and 53 per cent of the overall variance respectively.

Sand Equivalent

A comparison of the sand equivalent variances are shown in the following table. The reader is referred to page 6 for an explanation of Jr-2 duplicate sample distribution for testing.

	Pit Le-111	Pit Jr-2			
		Boise	Moscow	Boise and Moscow	All
Arith. Ave.	65.38	42.88	36.29	39.99	39.85
Mat. Var.	7.29	7.77	2.62		6.68
Sam. Var.	4.09	6.48	4.60	40.03	22.45
Tes. Var.	1.51	1.85	0.96	1.76	1.59
Overall Var.	12.89	16.10	8.18	41.79	30.72
Overall Sigma	3.59	4.01	2.86	6.46	5.54

As mentioned earlier, the Moscow Laboratory cross-split their samples before testing whereas the Boise Laboratory used only a single-split before testing their samples. The splitting method used is reflected in the testing variance of both laboratories. Moscow had a testing variance of 0.96 whereas Boise had a testing variance of 1.85. This reaffirms the findings in the gradation study that cross-splitting produces a lower testing variance.

The large difference in the Jr-2 arithmetic average values between the Boise and Moscow Laboratories was not expected. This difference noticeably affected the sampling variances. A review of testing procedures showed that the material was subjected to severe rather than normal shaking at the Moscow Laboratory. A series of reference check tests was then initiated between the Boise, Moscow, and Pocatello Laboratories to see if this strong shaking was the cause of the discrepancies. Forty-five samples were tested for their sand equivalent value, fifteen samples being supplied from each laboratory for this check. Five samples, four from one laboratory, were omitted because of wide discrepancies in their test results. These discrepancies were probably due to improper sample preparation which did not produce essentially identical samples. The results of the series of reference check tests are shown in Table 11 (Appendix).

In the original test run, the Moscow Laboratory was biased on the low side by a value of approximately 6.5 from the Boise Laboratory.

The series of reference check tests also showed the Moscow Laboratory to be low with respect to the Boise Laboratory. However, the variation between the two was not as great averaging 3.33 or nearly one-half of the original spread. This would indicate that the severe shaking was the cause of the large difference between the two in the original test run. The average variation between the Boise and Pocatello Laboratories was approximately 3.43 whereas the average spread between the Moscow and Pocatello Laboratories was approximately 2.63. The Boise Laboratory was biased on the high side with respect to both the Moscow and Pocatello Laboratories whereas the Moscow Laboratory was biased on the low side with respect to the Pocatello Laboratory.

REFERENCES

1. The Statistical Approach to Quality Control in Highway Construction, U. S. Department of Commerce, Bureau of Public Roads, April, 1965.

2. Development of Improved Quality Control Through Statistical Analysis of Highway Tests and Measurements, A Research Proposal by the Montana Highway Commission, May 1, 1964.

APPENDIX

TABLE 1

Random Sampling Schedule at Pit Le-111

Sample Number*	Date	Time
101	8-3-64	11:05 AM
102		11:10 AM
103		11:15 AM
104		11:20 AM
105		11:25 AM
106		11:30 AM
107	same	11:35 AM
108		11:40 AM
109		1:55 PM
110		2:00 PM
111		2:15 PM
112		2:20 PM
113	same	2:30 PM
114		2:35 PM
115		2:40 PM
116		3:05 PM
117		3:10 PM
118		3:15 PM
119	same	3:25 PM
120		3:30 PM
121		3:40 PM
122		3:55 PM
123		4:05 PM
124		4:15 PM
125		4:20 PM
126	8-4-64	10:20 AM
127		10:25 AM
128		10:45 AM
129		10:55 AM
130		11:00 AM
131		11:10 AM
132	same	11:20 AM
133		11:25 AM
134		11:30 AM

* Each sample obtained in duplicate. Gravel samples are numbered in a series beginning with 101 to 200. Therefore, sample 1 is termed 101.

TABLE 2

Random Sampling Schedule at Pit Jr-2

Sample Number*	Date	Time
101	7-27-65	10:02 AM
102	7-27-65	10:30 AM
103	7-27-65	10:36 AM
104	7-27-65	10:45 AM
105	7-27-65	10:58 AM
106	7-27-65	11:12 AM
107	7-27-65	11:18 AM
- - - - - - - - - -	BREAKDOWN	- - - - - - - -
108	7-27-65	12:40 PM
109	7-27-65	12:47 PM
- - - - - - - - - -	BREAKDOWN	- - - - - - - -
110	7-27-65	1:38 PM
111	7-27-65	1:44 PM
- - - - - - - - - -	BREAKDOWN	- - - - - - - -
112	8-3-65	8:20 AM
113	8-3-65	8:35 AM
114	8-3-65	9:22 AM
115	8-3-65	9:55 AM
116	8-3-65	10:15 AM
117	8-3-65	10:30 AM
118	8-3-65	11:10 AM
119	8-3-65	11:25 AM
120	8-3-65	1:05 PM
121	8-3-65	1:22 PM
122	8-3-65	1:40 PM
123	8-3-65	2:06 PM
124	8-3-65	2:32 PM
125	8-3-65	3:04 PM
126	8-3-65	3:19 PM
127	8-3-65	3:51 PM
128	8-3-65	4:13 PM
- - - - - - - - - -	BREAKDOWN	- - - - - - - -

TABLE 2 Cont'd

Random Sampling Schedule at Pit Jr-2

Sample Number*	Date	Time
129	8-4-65	10:15 AM
130	8-4-65	10:47 AM
131	8-4-65	11:25 AM
132	8-4-65	12:53 AM
133	8-4-65	1:11 PM
134	8-4-65	1:26 PM
135	8-4-65	1:43 PM
136	8-4-65	2:02 PM
137	8-4-65	2:20 PM
138	8-4-65	2:35 PM
139	8-4-65	2:52 PM
140	8-4-65	3:07 PM
141	8-4-65	3:35 PM
142	8-4-65	3:54 PM
143	8-4-65	4:09 PM
144	8-4-65	4:30 PM
	- - - - - - - - - - BREAKDOWN - - - - - - - -	
145	8-5-65	8:15 AM
146	8-5-65	8:45 AM
147	8-5-65	9:07 AM
148	8-5-65	9:22 AM
149	8-5-65	9:39 AM
150	8-5-65	9:58 AM

* Each sample obtained in duplicate

TABLE 3

Statistical Results of Pit Le-111
(34 Samples)

% Passing Sieve			1 Sigma	±1 Sigma	±2 Sigma	±3 Sigma
	Arithmetic Mean	91.75				
	Material Variance	14.46	3.80	7.60	15.20	22.80
3/8 in.	Sampling Variance	7.38	2.72	5.44	10.88	16.32
	Testing Variance	0.30	0.548	1.10	2.19	3.28
	Overall Variance	22.13	4.70	9.40	18.80	28.20
	Overall Sigma	4.70				
	Arithmetic Mean	53.52				
	Material Variance	40.38	6.36	12.72	25.44	38.16
No. 4	Sampling Variance	22.93	4.79	9.58	19.16	28.74
	Testing Variance	0.42	0.65	1.30	2.60	3.90
	Overall Variance	63.73	7.98	15.96	31.92	47.88
	Overall Sigma	7.98				
	Arithmetic Mean	64.98				
	Material Variance	2.84	1.69	3.38	6.76	10.14
No. 8	Sampling Variance	4.03	2.01	4.02	8.04	12.06
	Testing Variance	2.41	1.55	3.10	6.20	9.30
	Overall Variance	9.29	3.05	6.10	12.20	18.30
	Overall Sigma	3.05				
	Arithmetic Mean	28.35				
	Material Variance	1.66	1.29	2.58	5.16	7.74
No. 50	Sampling Variance	3.40	1.84	3.68	7.36	11.04
	Testing Variance	0.82	.91	1.82	3.64	5.46
	Overall Variance	5.88	2.43	4.86	9.72	14.58
	Overall Sigma	2.43				
	Arithmetic Mean	16.66				
	Material Variance	0.52	.72	1.44	2.88	4.32
No. 200	Sampling Variance	1.29	1.14	2.28	4.56	6.84
	Testing Variance	0.40	.63	1.26	2.52	3.78
	Overall Variance	2.21	1.49	2.98	5.96	8.94
	Overall Sigma	1.49				
	Arithmetic Mean	65.38				
	Material Variance	7.29	2.70	5.40	10.80	16.20
Sand	Sampling Variance	4.09	2.04	4.08	8.16	12.24
Equivalent	Testing Variance	1.51	1.23	2.46	4.92	7.38
	Overall Variance	12.89	3.59	7.18	14.36	21.54
	Overall Sigma	3.59				

TABLE 4

Sample Distribution From Pit Jr-2

(50 Duplicate Samples, D_1 and D_2)

Boise D_1 & D_2	Moscow D_1 & D_2	Boise & Moscow D_1 & D_2	
Sample No.	Sample No.	Sample No.	
101	102	103	131
104	112	105	135
109	114	106	137
110	115	107	140
111	117	108	141
113	120	116	142
124	123	118	145
127	126	119	146
129	132	121	147
133	134	122	149
136	138	125	150
139	143	128	
144	148	130	

TABLE 5

Statistical Results of Pit Jr-2

% Passing Sieve		Boise	Moscow	Boise & Moscow	Boise & Moscow (Comb.)
		13 Samples	12 Samples	24 Samples	49 Samples
3/8 in.	Arithmetic Mean	63.06	60.28	62.62	62.17
	Material Variance	5.62	19.83	13.17	13.40
	Sampling Variance	0.98	2.94	0.56	1.26
	Testing Variance	6.37	2.49	3.80	4.16
	Overall Variance	12.97	25.26	17.54	18.82
	Overall Sigma	3.60	5.03	4.19	4.34
		13 Samples	12 Samples	24 Samples	49 Samples
No. 4	Arithmetic Mean	48.83	46.15	48.81	48.16
	Material Variance	13.32	32.05	21.00	21.98
	Sampling Variance	2.25	5.18	0.60	2.16
	Testing Variance	5.16	1.89	3.76	3.67
	Overall Variance	20.72	39.13	25.36	27.81
	Overall Sigma	4.55	6.26	5.04	5.27
		13 Samples	13 Samples	24 Samples	50 Samples
No. 8	Arithmetic Mean	80.73	80.93	81.67	81.23
	Material Variance	7.10	4.75	6.85	6.26
	Sampling Variance	0.64	1.61	0.75	0.95
	Testing Variance	1.29	2.09	1.26	1.48
	Overall Variance	9.02	8.46	8.86	8.69
	Overall Sigma	3.00	2.91	2.98	2.95
		13 Samples	13 Samples	24 Samples	50 Samples
No. 50	Arithmetic Mean	28.06	29.03	28.28	28.40
	Material Variance	3.53	1.90	6.50	4.51
	Sampling Variance	2.91	0.12	1.17	1.40
	Testing Variance	1.13	1.03	0.91	1.00
	Overall Variance	7.58	3.05	8.58	6.92
	Overall Sigma	2.75	1.75	2.93	2.63
		13 Samples	13 Samples	24 Samples	50 Samples
No. 200	Arithmetic Mean	16.85	17.08	17.08	17.02
	Material Variance	1.30	0.73	1.64	1.23
	Sampling Variance	3.09	0.66	1.94	1.91
	Testing Variance	0.60	0.43	0.52	0.52
	Overall Variance	4.99	1.83	4.10	3.66
	Overall Sigma	2.23	1.35	2.02	1.91
		13 Samples	12 Samples	24 Samples	49 Samples
Sand Equivalent	Arithmetic Mean	42.88	36.29	39.99	39.85
	Material Variance	7.77	2.62	0	6.68
	Sampling Variance	6.48	4.60	40.03	22.45
	Testing Variance	1.85	0.96	1.76	1.59
	Overall Variance	16.10	8.18	41.79	30.72
	Overall Sigma	4.01	2.86	6.47	5.54

TABLE 6

Statistical Results of Pit Jr-2

			Boise and Moscow					Boise - Moscow (Combined)			
			1	2	4	6		1	2	4	6
% Passing			Sigma	Sigma	Sigma	Sigma		Sigma	Sigma	Sigma	Sigma
	Arithmetic Mean	62.62					62.17				
	Material Variance										
3/8 in.	Sampling Variance										
	Testing Variance										
	Overall Variance										
	Arithmetic Mean	48.81					48.16				
	Material Variance										
No. 4	Sampling Variance										
	Testing Variance										
	Overall Variance	25.36	5.04	10.08	20.16	30.24					
	Arithmetic Mean	81.67					81.23				
	Material Variance	6.85	2.62	5.24	10.48	15.72	6.26	2.50	5.00	10.00	15.00
No. 8	Sampling Variance	0.75	0.87	1.74	3.48	5.22	0.95	0.97	1.94	3.88	5.82
	Testing Variance	1.26	1.12	2.24	4.48	6.72	1.48	1.22	2.44	4.88	7.32
	Overall Variance	8.86	2.98	5.96	11.92	17.88	8.69	2.95	5.90	11.80	17.70
	Arithmetic Mean	28.28					28.40				
	Material Variance	6.50	2.55	5.10	10.20	15.30	4.51	2.12	4.24	8.48	12.72
No. 50	Sampling Variance	1.17	1.08	2.16	4.32	6.48	1.40	1.18	2.36	4.72	7.08
	Testing Variance	0.91	0.95	1.90	3.80	5.70	1.00	1.00	2.00	4.00	6.00
	Overall Variance	8.58	2.93	5.86	11.72	17.58	6.92	2.63	5.26	10.52	15.78
	Arithmetic Mean	17.08					17.02				
	Material Variance	1.64	1.28	2.56	5.12	7.68	1.23	1.11	2.22	4.44	6.66
No. 200	Sampling Variance	1.94	1.39	2.78	5.56	8.34	1.91	1.38	2.76	5.52	8.28
	Testing Variance	0.52	0.72	1.44	2.88	4.32	0.52	0.72	1.44	2.88	4.32
	Overall Variance	4.10	2.03	4.06	8.12	12.18	3.66	1.91	3.82	7.64	11.46
	Arithmetic Mean	39.99					39.85				
	Material Variance										
Sand Equiv.	Sampling Variance										
	Testing Variance										
	Overall Variance										

TABLE 6 Cont'd

Statistical Results of Pit Jr-2

% Passing			Boise 1 Sigma	Boise 2 Sigma	Boise 4 Sigma	Boise 6 Sigma		Moscow 1 Sigma	Moscow 2 Sigma	Moscow 4 Sigma	Moscow 6 Sigma
3/8 in.	Arithmetic Mean	63.06					60.28				
	Material Variance	5.62	2.37	4.74	9.48	14.82	19.83	4.45	8.90	17.80	26.70
	Sampling Variance	0.98	0.99	1.98	3.96	5.94	2.94	1.72	3.44	6.88	10.32
	Testing Variance	6.37	2.52	5.04	10.08	15.12	2.49	1.58	3.16	6.32	9.48
	Overall Variance	12.97	3.60	7.20	14.40	21.60	25.26	5.03	10.06	20.12	30.18
	Overall Sigma	3.60					5.03				
No. 4	Arithmetic Mean	48.83					46.15				
	Material Variance	13.32	3.65	2.32	4.64	6.96	32.05	5.66	11.32	22.64	33.96
	Sampling Variance	2.25	1.50	3.00	6.00	9.00	5.18	2.28	4.56	9.12	13.68
	Testing Variance	5.16	2.27	4.54	9.18	13.62	1.89	1.38	2.76	5.52	7.68
	Overall Variance	20.72	4.55	9.10	18.20	27.30	39.13	6.26	12.52	25.04	37.45
	Overall Sigma	4.55					6.26				
No. 8	Arithmetic Mean	80.73					80.93				
	Material Variance	7.10	2.67	5.34	10.68	16.02	4.75	2.18	4.36	8.72	13.08
	Sampling Variance	0.64	.80	1.60	3.20	4.80	1.61	1.27	2.54	5.08	7.62
	Testing Variance	1.29	1.14	2.28	4.56	6.84	2.09	1.45	2.90	5.80	7.62
	Overall Variance	9.02	3.00	6.00	12.00	18.00	8.46	2.91	5.82	11.64	17.46
	Overall Sigma	3.00					2.91				
No. 50	Arithmetic Mean	28.06					29.03				
	Material Variance	3.53	1.88	3.76	7.52	11.28	1.90	1.38	2.76	5.52	8.88
	Sampling Variance	2.91	1.71	3.42	6.84	10.26	0.12	.35	.70	1.40	2.10
	Testing Variance	1.13	1.05	2.10	4.20	6.30	1.03	1.02	2.04	4.08	6.12
	Overall Variance	7.58	2.75	5.50	11.00	16.50	3.05	1.75	3.50	7.00	10.50
	Overall Sigma	2.75					1.75				

TABLE 6 Cont'd

Statistical Results of Pit Jr-2

			Boise					Moscow			
			1	2	4	6		1	2	4	6
% Passing			Sigma	Sigma	Sigma	Sigma		Sigma	Sigma	Sigma	Sigma
No. 200	Arithmetic Mean	16.85					17.08				
	Material Variance	1.30	1.14	2.28	4.56	6.84	0.73	0.85	1.70	3.40	5.10
	Sampling Variance	3.09	1.76	3.52	7.04	10.56	0.66	0.81	1.62	3.24	4.86
	Testing Variance	0.60	0.77	1.54	3.08	4.62	0.43	0.66	1.32	2.84	3.96
	Overall Variance	4.99	2.23	4.46	8.92	13.38	1.83	1.35	2.70	5.40	8.10
	Overall Sigma	2.23					1.35				
Sand Equiv.	Arithmetic Mean	42.88					36.29				
	Material Variance	7.77	2.79	5.58	11.16	16.74	2.62	1.62	3.24	6.48	9.72
	Sampling Variance	6.48	2.55	5.10	10.20	15.30	4.60	2.14	4.28	8.56	12.84
	Testing Variance	1.85	1.36	2.72	5.44	8.16	0.96	0.98	1.96	3.92	5.88
	Overall Variance	16.10	4.01	8.02	16.04	24.06	8.18	2.86	5.72	11.44	17.16
	Overall Sigma	4.01					2.86				

TABLE 7

Coefficient of Variation - Pit Jr-2

These values show the variation in the overall results for the mechanical analysis and sand equivalent. These are variations in results at each laboratory, not between laboratories.

$$C.\ V. = \frac{\sigma\ 100}{X}$$

Material, % Passing	Boise	Moscow
3/8 in.	5.70	8.35
No. 4	9.33	13.6
No. 8	3.72	3.60
No. 50	9.80	6.04
No. 200	13.2	7.90
Sand Equivalent	9.36	7.88

TABLE 8

Testing Variance Comparison

Grain Size, % Passing	Pit Le-111	Pit Jr-2 Boise	Moscow	Boise & Moscow (24)	Boise & Moscow (all, 50)
3/8 in.	0.30	6.37	2.49	3.80	4.16
No. 4	0.42	5.16	1.89	3.76	3.67
No. 8	2.41	1.29	2.09	1.26	1.48
No. 50	0.82	1.13	1.03	0.91	1.00
No. 200	0.40	0.60	0.43	0.52	0.52
Sand Equivalent	1.51	1.85	0.96	1.76	1.59

TABLE 9

Sampling Variance Comparison

Grain Size, % Passing	Pit Le-111	Pit Jr-2 Boise	Moscow	Boise & Moscow (24)	Boise & Moscow (all, 50)
3/8 in.	7.38	0.98	2.94	.56	1.26
No. 4	22.93	2.25	5.18	.60	2.16
No. 8	4.03	0.64	1.61	0.75	0.95
No. 50	3.40	2.91	0.12	1.17	1.40
No. 200	1.29	3.09	0.66	1.94	1.91
Sand Equivalent	4.09	6.48	4.60	4.03	22.45

TABLE 10

Material Variance Comparison

Grain Size, % Passing	Pit Le-111	Pit Jr-2 Boise	Pit Jr-2 Moscow	Pit Jr-2 Boise & Moscow (24)	Pit Jr-2 Boise & Moscow (all, 50)
3/8 in.	14.46	5.62	19.83	13.17	13.40
No. 4	40.38	13.32	32.05	21.00	21.98
No. 8	2.84	7.10	4.75	6.85	6.26
No. 50	1.66	3.53	1.90	6.50	4.51
No. 200	0.52	1.30	0.73	1.64	1.23
Sand Equivalent	7.29	7.77	2.61	0	6.68

TABLE 11

Results of Sand Equivalent Testing Reference Check

	Sand Equivalent Results				Deviation From Average		
Lab. Number	Boise	Moscow	Pocatello	Average	Boise	Moscow	Pocatello
43242	62	62	58	60.7	+1.3	+1.3	-2.7
42919	28	26	29	27.7	+0.3	-1.7	+1.3
42922	38	38	40	38.7	-0.7	-0.7	+1.3
42921	40		45	41.3	-1.3	-2.3	+3.7
43167	50	50	45	48.3	+1.7	+1.7	-3.3
42923	32	32	32	32.0	--	--	--
43157	27	27	27	27.0	--	--	--
42920	21	24	26	23.7	-2.7	+0.3	+2.3
43296	32	31	29	30.7	+1.3	+0.3	-1.7
43237	42	37	41	40.0	2.0	-3.0	+1.0
43062	83	78	76	79.0	+4.0	-1.0	-3.0
43295	36	33	31	33.3	+2.7	-0.3	-2.3
43294	32	31	33	32.0	--	-1.0	+4.0
43064	45	43	42	43.3	+1.7	-0.3	-1.3
210069	47	45	46	46.0	+1.0	-1.0	--
210924	66	65	66	65.7	+0.3	-0.7	+0.3
210774	54	44	44	47.3	+6.7	-3.3	-3.3
210895	89	91	92	90.7	-1.7	+0.3	+1.3
210916	40	44	47	43.7	-3.7	+0.3	+3.3
210070	41	41	47	43.0	-2.0	-2.0	+4.0
210039	54	50	52	52.0	+2.0	-2.0	--
210914	47	50	54	50.3	-3.3	-0.3	+3.7

TABLE 11 Cont'd

Results of Sand Equivalent Testing Reference Check

Lab. Number	Sand Equivalent Results: Boise	Moscow	Pocatello	Average	Deviation From Average: Boise	Moscow	Pocatello
210072	53	57	55	55.0	-2.0	+2.0	--
211077	19	22	19	20.0	-1.0	+2.0	-1.0
210913	52	60	60	57.3	-5.3	+2.7	+2.7
209513	52	44	47	47.7	+4.3	-3.7	-0.7
210773	71	61	67	66.3	+4.7	-5.3	+0.7
210052	62	62	65	63.0	-1.0	-1.0	+2.0
209512	68	65	67	66.7	+1.3	-1.7	+0.3
47680	65	66	67	66.0	-1.0	--	+1.0
47712	38	38	36	37.3	+0.7	+0.7	-1.3
47711	54	50	49	51.0	+3.0	-1.0	-2.0
48175	64	54	63	60.3	+3.7	-6.3	+2.7
47667	79	78	77	78.0	+1.0	--	-1.0
47790	63	58	59	60.0	+3.0	-2.0	-1.0
47794	65	55	58	59.3	5.7	-4.3	-1.3
48366	67	65	70	67.3	-0.3	-2.3	+2.7
48423	70	70	73	71.0	-1.0	-1.0	+2.0
48576	65	59	59	61.0	+4.0	-2.0	-2.0
48664	63	54	61	59.3	+3.7	-5.3	+1.7